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EVALUATION OF AIRCRAFT LANDING GEAR GROUND FLOTATION CHARACTERISTICS FOR OPERATION FROM UNSURFACED SOIL AIRFIELDS

DONALD H. GRAY

DONALD E. WILLIAMS

TECHNICAL REPORT ASD-TR-68-34

SEPTEMBER 1968

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ASD-TR-68-34

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DONALD H. GRAY

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FOREWORD

The work reported here has evolved from a need to establish flotation requirements for several proposed systems and numerous flotation capability studies for existing aircraft in support of the ASD mission.

This report was submitted by the authors in May 1968.

This technical report is published for use, within the ASD environment, as a standard method in evaluating aircraft ground flotation capabilities of present and proposed air-vehicle designs operating from unsurfaced soil airfields.

Publication of this report does not constitute Air Force approval of the report's findings or conclusions. It is published only for the exchange and stimulation of ideas.

William A. Hamilton

WILLIAM A. HAMILTON
Chief, Launching & Alighting Division
Directorate of Airframe Subsystems
Engineering

ABSTRACT

This report presents a theoretical method of evaluating aircraft landing gear ground flotation characteristics on unsurfaced soil airfields. Equations developed in AFFDL-TR-66-43, Part I, Aircraft Ground Flotation Investigation, form the basis for the method used in this report.

It contains a list of definitions of terms used in regard to ground flotation within ASD and presents a method of evaluating the ground flotation characteristics and capabilities of aircraft to operate from unsurfaced soil airfields. The method presented is relatively straightforward and is applicable to most aircraft having conventional landing gear configurations. A sample calculation is also presented.

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SYMBOLS

A	Single tire contact area (square inches)
AP	Aircraft passes
B	Lateral distance between centerlines of the most inboard and most outboard tires of one main landing gear assembly (inches)
b	Tire deflection (percent)
C	Coverage
CBR	California Bearing Ratio (percent)
CBR_1	CBR required for one coverage
CP	Contact pressure - not inflation pressure (pounds per square inch)
D	Lateral distance between the centerlines of the most outboard tires of the nose landing gear assembly (inches)
DWL	Dynamic wheel loads (kips)
D_F	Wheel flange diameter (inches) (bead dia. +2 times flange height)
D_o	Tire outside diameter-nominal for new tires (inches)
d	Tire radial deflection (inches)
E	Lateral distance between centerlines of the left and right main landing gear assembiies (inches)
ESWL	Equivalent single wheel load (kips)
F	Forward to aft distance between the centerlines of the main and nose landing gear assemblies (inches)
GW	Gross weight of aircraft (pounds)
H	Aircraft passes correction factor due to main landing gear spacing
J	Height of CG (at gross weight under consideration)
K	Aircraft passes correction factor due to relative spacing of main and nose landing gear assemblies
L	Distance maximum forward CG (at gross weight under consideration) is aft of nose landing gear centerline (inches)
M	Distance maximum aft CG (at gross weight under consideration) is forward of main landing gear centerline (inches)

SYMBOLS (CONTD)

N	Number of tires of a landing gear assembly
P	Passes
P/C	Passes per coverage ratio
R	Tire contact area radius (inches) $R = .564 \sqrt{A}$
SWL	Single wheel load (kips)
W	Width of single tire contact area (inches) $W = .875 \sqrt{A}$
w	Tire section width - nominal for new tires (inches)

Subscript Symbols

M	Main landing gear factor
N	Nose landing gear factor

DEFINITION OF TERMS

Assembly Load

The landing gear assembly load used for ground flotation calculations shall be that static load which results from the specified aircraft gross weight condition.

California Bearing Ratio (CBR)

A measure of the bearing capacity of soil. The CBR of a soil is expressed in terms of a percentage of the bearing capacity of a standard crushed limestone surface. Details of test procedures used to determine the CBR of a soil are contained in MIL-STD-621.

Coverage (C)

This term when applied to a point means one movement of the wheel over that point. Coverage of an area is defined as the covering of every point in the area.

Equivalent Single Wheel Load (ESWL)

The theoretical load which, if acting on a single tire, with a contact area equal to that of one tire of the assembly, will produce the same effect on the airfield as the multiple wheel assembly.

Pass or Aircraft Pass (P) or (AP)

A movement or passage of the aircraft past a given lateral station.

Single Wheel Load (SWL)

The calculated load on each tire of a landing gear assembly. It is computed by dividing the assembly load by the number of tires on the assembly.

Tire Contact Area (A)

The calculated area of the tire footprint which is in contact with the airfield surface.

SECTION I

INTRODUCTION

This report is to provide an interim standard for evaluation of aircraft landing gear designs proposed for operation on unsurfaced soils. The report is published to give preliminary guidance for design of advanced systems.

The method contained herein may be used to evaluate relative ground flotation performance for aircraft operation in the conventional takeoff and landing (CTOL) or short field takeoff and landing (STOL) mode on unsurfaced soils. Ground flotation performance is expressed in terms of the number of operations that could be performed on a heavy clay soil prior to formation of permanent rutting to a depth of about three inches. The method allows consideration of single wheel loads in the range of 5000 to 75,000 pounds and tire contact pressures in the range of 20 to 300 pounds per square inch.

This report, when specified, supersedes the Theater of Operations airfield ground flotation evaluation procedures contained in AFSCM 80-1, Handbook of Instructions for Aircraft Design.

The general procedure for evaluation of landing gear flotation for operation from unsurfaced soils consists of computation of the number of passes that the aircraft should be able to perform on a specified strength airfield prior to attainment of a defined failure condition. The number of passes predicted is then compared with the required number of passes to determine if the landing gear is acceptable. Due to the many variables involved, it is essential that a standard calculation procedure be used.

SECTION II

AIRCRAFT GROUND FLOTATION ANALYSIS

The following has been developed as an interim standard procedure:

Determination of Single Wheel Load (SWL)

Main Landing Gear Wheels — Analyze the aircraft at the specified gross weight condition and the most critical center of gravity position (most critical for ground flotation), using Figure 1a to determine the individual landing gear assembly loads. Divide the assembly load by the number of tires per assembly to determine the single wheel load.

Nose Landing Gear Wheels — Analyze the aircraft at the specified gross weight condition and the most critical center of gravity position (most critical for overall aircraft ground flotation) to determine the dynamic load on the nose landing gear assembly due to braking at a deceleration rate of 10 feet/second/second. The procedure outlined in Figure 1b will be used. The assembly load is divided by the number of tires on the assembly to determine the single wheel load.

Tire Inflation Pressure

The tire inflation pressure used for ground flotation analysis should be the pressure required to support the most severe loading condition without exceeding the specified tire deflection limits. Therefore, in the following ground flotation analysis, loads resulting from a maximum forward center of gravity (CG) position will be used in nose landing gear tire inflation pressure calculations and, accordingly, the main landing gear tire inflation pressures will be based on main landing gear loads resulting from an aft CG position.

The following calculations should be m... for both the main and nose gear assemblies.

Determination of Tire Contact Area (A)

Tire contact area shall be determined by use of the following relations:

$$A = 2.36d\sqrt{(D_0 - d)(w - d)} \quad \text{and}$$

$$d - \frac{b(D_o - D_F)}{200}$$

where A = Tire contact area

d = Tire radial deflection in inches

D_o = Tire outside diameter in inches

w = Tire section width in inches

b = Tire deflection under consideration in per cent

D_F = Wheel flange diameter in inches

Tire Contact Pressure (CP)

Tire contact pressure is determined by dividing the single wheel load by the calculated contact area.

Equivalent Single Wheel Load (ESWL)

Figure 2 is used to determine the equivalent single wheel load. Determine the center to center spacing in radii by dividing the actual tire spacing by the radius of a circle of area equal to the single tire contact area. Increase the single wheel load for each adjacent wheel by the percentage indicated by Figure 2 to determine the equivalent single wheel load. This adjacent wheel may be "adjacent" by virtue of either a twin or tandem wheel arrangement. In either case, if it is more than 5 1/2 single tire contact area radii from the wheel under consideration, it will not be considered in determining the equivalent single wheel load. Note that in the case of a landing gear with a single isolated wheel, the equivalent single wheel load is equal to the single wheel load.

Coverages (C)

Enter Figure 3 with the equivalent single wheel load and tire contact pressure of the assembly in question to determine a value of CBR_1. The

number of coverages to failure of the airfield is then determined by the following relation:

$$\text{Coverages} = \left(\frac{CBR}{CBR_I}\right)^6$$

Where CBR is the strength of the airfield under consideration.

(Figure 4 can be used to simplify this calculation.)

Passes Per Coverage Ratio (P/C)

Use the procedures of Figure 5 to determine the passes per coverage for the assembly under consideration.

Passes (P)

Multiply the number of coverages by the passes per coverage ratio to determine the number of passes that the assembly can accomplish prior to failure of the airfield.

Aircraft Passes (AP)

Use the procedures of Figure 6 to determine the number of passes of the aircraft that can be accomplished prior to failure of the airfield.

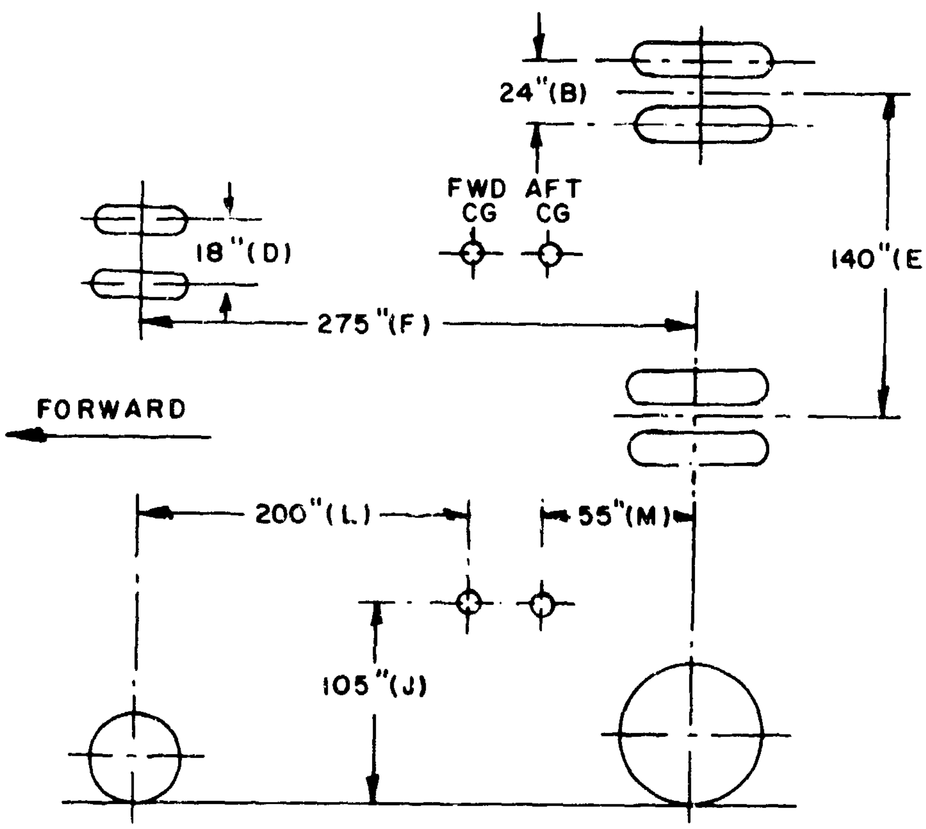
SECTION III

SAMPLE CALCULATIONS

EXAMPLE SITUATION

How many passes can an aircraft weighing 60,000 pounds and configured as below make on an unprepared airfield with CBR of 4 without failure of the surface provided the tires are allowed to operate 50% deflected.

Nose Tires - 9.50-16 Type III	Main Tires - 12.50-16 Type III
D_o = 33.4"	D_o = 38.5"
D_F = 18.0"	D_F = 18.5"
b = 50%	b = 50%
w = 9.7"	w = 12.75"



Example Configuration

a. Single Wheel Load Calculation (SWL) - Reference Figure 1

Main Wheels:

$$SWL_M = \frac{GW \times (F - M)}{F \times N_M}$$

$$= \frac{60{,}000\ (275-55)}{275 \times 4}$$

$$= 12{,}000 \text{ lbs}$$

Nose Wheels:

$$SWL_N = \frac{GW \times (F-L)}{F \times N_N} + \frac{10 \times GW \times J}{32.2 \times F \times N_N}$$

$$= \frac{60{,}000\ (275-200)}{275 \times 2} + \frac{10 \times 60{,}000 \times 105}{32.2 \times 275 \times 2}$$

$$= 8{,}180 + 3{,}550$$

$$= 11{,}730 \text{ lbs}$$

b. Single Tire Contact Area (A)

Main Wheels:

$$d = \frac{b\ (D_o - D_F)}{200}$$

$$= \frac{50\ (38.5-18.5)}{200}$$

$$= 5.0'' \text{ deflection}$$

$$A = 2.36d\sqrt{(D_o - d)(w - d)}$$

$$= 2.36 \times 5\sqrt{(38.5-5)(12.75-5)}$$

$$= 190 \text{ sq in}$$

Nose Wheels:

$$d = \frac{b\ (D_o - D_F)}{200}$$

$$= \frac{50\ (33.4-18)}{200}$$

$$= 3.85'' \text{ deflection}$$

$$A = 2.36d\sqrt{(D_o - d)(w - d)}$$

$$= 2.36 \times 3.85\sqrt{(33.4-3.85)(9.7-3.85)}$$

$$= 119.5 \text{ sq in}$$

c. Contact Pressure Calculation (CP)

Main Wheels:

$$P_M = \frac{SWL_M}{A_M}$$

$$= \frac{12{,}000}{190}$$

$$= 63 \text{ psi}$$

Nose Wheels:

$$P_N = \frac{SWL_N}{A_N}$$

$$= \frac{11{,}730}{119.5}$$

$$= 98.1 \text{ psi}$$

d. Equivalent Single Wheel Load Calculations (ESWL) - Reference Figure 2

Main Wheels:

Single tire contact area radius —

$$R_M = .564\sqrt{A}$$

$$= .564\sqrt{190}$$

$$= 7.78 \text{ inches}$$

$$\frac{B}{R_M} = \frac{24}{7.8} = 3.08 \text{ radii}$$

$$ESWL_M = SWL_M + (\text{Fig 2 Factor})$$

$$= 12{,}000 + 53\%$$

$$= 18{,}350 \text{ lbs}$$

Nose Wheels:

Single tire contact area radius —

$$R_N = .564\sqrt{A}$$

$$= .564\sqrt{119.8}$$

$$= 6.17 \text{ inches}$$

$$\frac{D}{R_N} = \frac{18}{6.17} = 2.92 \text{ radii}$$

$$ESWL_N = SWL_N + (\text{Fig 2 Factor})$$

$$= 11{,}730 + 59\%$$

$$= 18{,}650 \text{ lbs}$$

e. Coverages Calculations (C) - Reference Figures 3 and 4

Main Wheels:

From Fig 3 with

$$ESWL_M = 18{,}350 \text{ lbs}$$

$$P = 63 \text{ psi}$$

Obtain $CBR_I = 2.4$

$$C_M = \left(\frac{CBR}{CBR_I}\right)^6$$

$$= \left(\frac{4}{2.4}\right)^6$$

$$= (1.67)^6$$

$$= 21 \text{ coverages}$$

Nose Wheels:

From Fig 3 with

$$ESWL_N = 18{,}650 \text{ lbs}$$

$$P = 98 \text{ psi}$$

Obtain $CBR_I = 3.7$

$$C_N = \left(\frac{CBR}{CBR_I}\right)^6$$

$$= \left(\frac{4}{3.7}\right)^6$$

$$= (1.08)^6$$

$$= 1.6 \text{ coverages}$$

f. Passes per Coverage Ratio Calculations (P/C) - Reference Figure 5

Main Wheels:

$$P/C = \frac{B + 80 + W_M}{.75\ N_M W_M}$$

$$= \frac{24 + 80 + .874\sqrt{190}}{.75 \times 2 \times .874\sqrt{190}}$$

$$= \frac{116.0}{18.2}$$

$$= 6.4\ P/C$$

Nose Wheels:

$$P/C = \frac{D + 80 + W_N}{.75\ N_N W_N}$$

$$= \frac{18 + 80 + .874\sqrt{119}}{.75 \times 2 \times .874\sqrt{119}}$$

$$= \frac{107}{14.3}$$

$$= 7.5\ P/C$$

g. Passes Calculation (P)

Main Wheels:

$$P_M = 21 \times 6.4 = 134 \text{ passes}$$

NOSE Wheels:

$$P_N = 1.6 \times 7.5 = 12 \text{ passes}$$

Aircraft Passes Calculations (AP) - Reference Figure 6

$$X = E - W_M - B$$

$$= 140 - 12.75 - 24$$

$$= 103$$

from Fig 6 (B)

$$H = 80$$

$$Y = \frac{E - W_M - W_N - B - D}{2}$$

$$= \frac{140 - 12.75 - 9.7 - 24 - 18}{2}$$

$$= 38$$

from Fig 6 (C)

$$K = 38$$

h. Aircraft Passes Calculations (AP) (Continued)

Main Wheels:

$$AP_M = \frac{80\ P_M\ P_N}{80P_N + (80-H)P_N + (80-K)P_M}$$

$$= \frac{80 \times 134 \times 12}{(80 \times 12) + (80-80)12 + (80-38)134}$$

$$= \frac{128{,}640}{960 + 0 + 5628}$$

$$= \frac{128{,}640}{6{,}588}$$

$$= 19.5 \text{ aircraft passes}$$

Nose Wheels:

$$AP_M = \frac{80\ P_M\ P_N}{80P_M + (80-H)P_N + (80-K)P_N}$$

$$= \frac{80 \times 134 \times 12}{(80 \times 134) + (80-80)12 + (80-38)12}$$

$$= \frac{128{,}640}{10{,}720 + 0 + 504}$$

$$= \frac{128{,}640}{11{,}224}$$

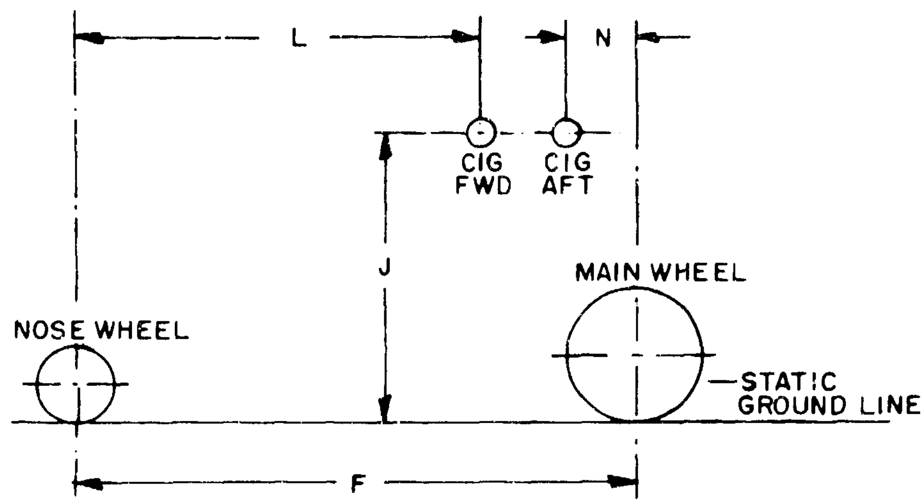
$$= 11.5 \text{ aircraft passes}$$

SOLUTION

Comparing the calculated values of AP_M and AP_N, paragraph h, it is indicated that the aircraft in question could make 11 passes on an unprepared surface having a CBR of 4.

APPENDIX

PERTINENT DIAGRAMS AND CURVES



a. Main Gear - Single Wheel Static Load

$$SWL_M = \frac{GW \times (F-M)}{F \times N_M}$$

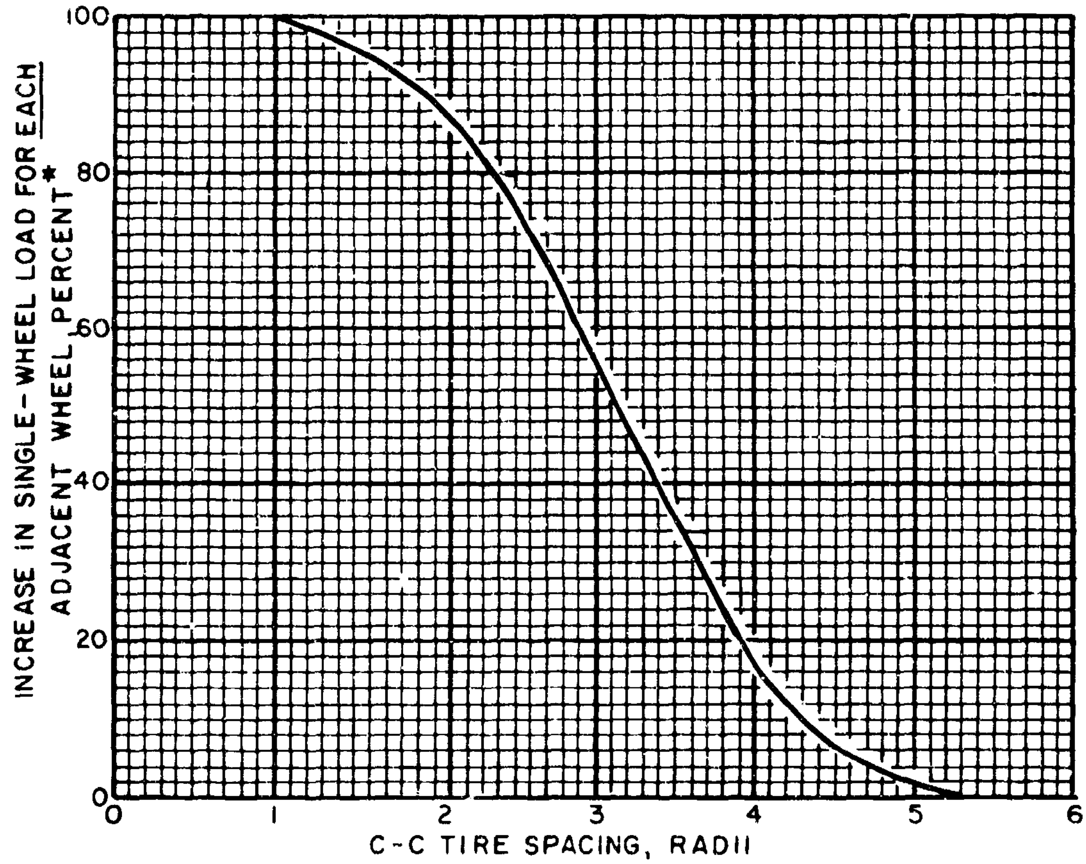
Where:
GW = Aircraft Gross Weight
N_M = Number of main wheels on aircraft

b. Nose Gear - Single Wheel Dynamic Load

$$SWL_N = \frac{GW \times (F-L)}{F \times N_N} + \frac{10 \times GW \times J}{32.2 \times F \times N_N}$$

Where
GW = Aircraft Gross Weight
N_N = Number of nose wheels

Figure 1. Single Wheel Loads



* Increase in load on a single wheel of a multiple-wheel gear to account for effects of adjacent wheels of the Multiple-wheel gear in arriving at an equivalent single-wheel load.

Figure 2. Equivalent Single-Wheel Load-Adjustment Curve For Unsurfaced Soils

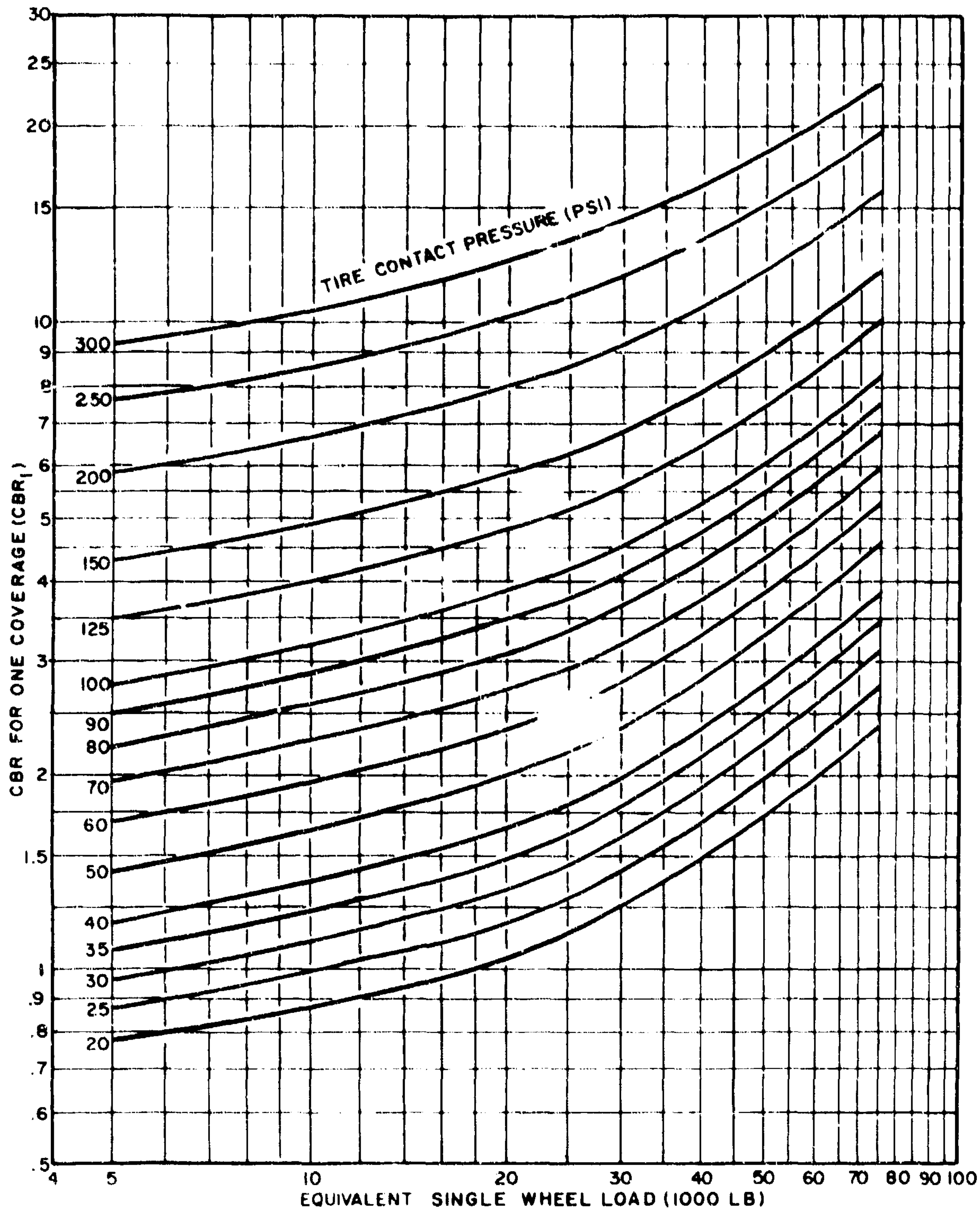


Figure 3. Equivalent Single Wheel Load (1000 lb)

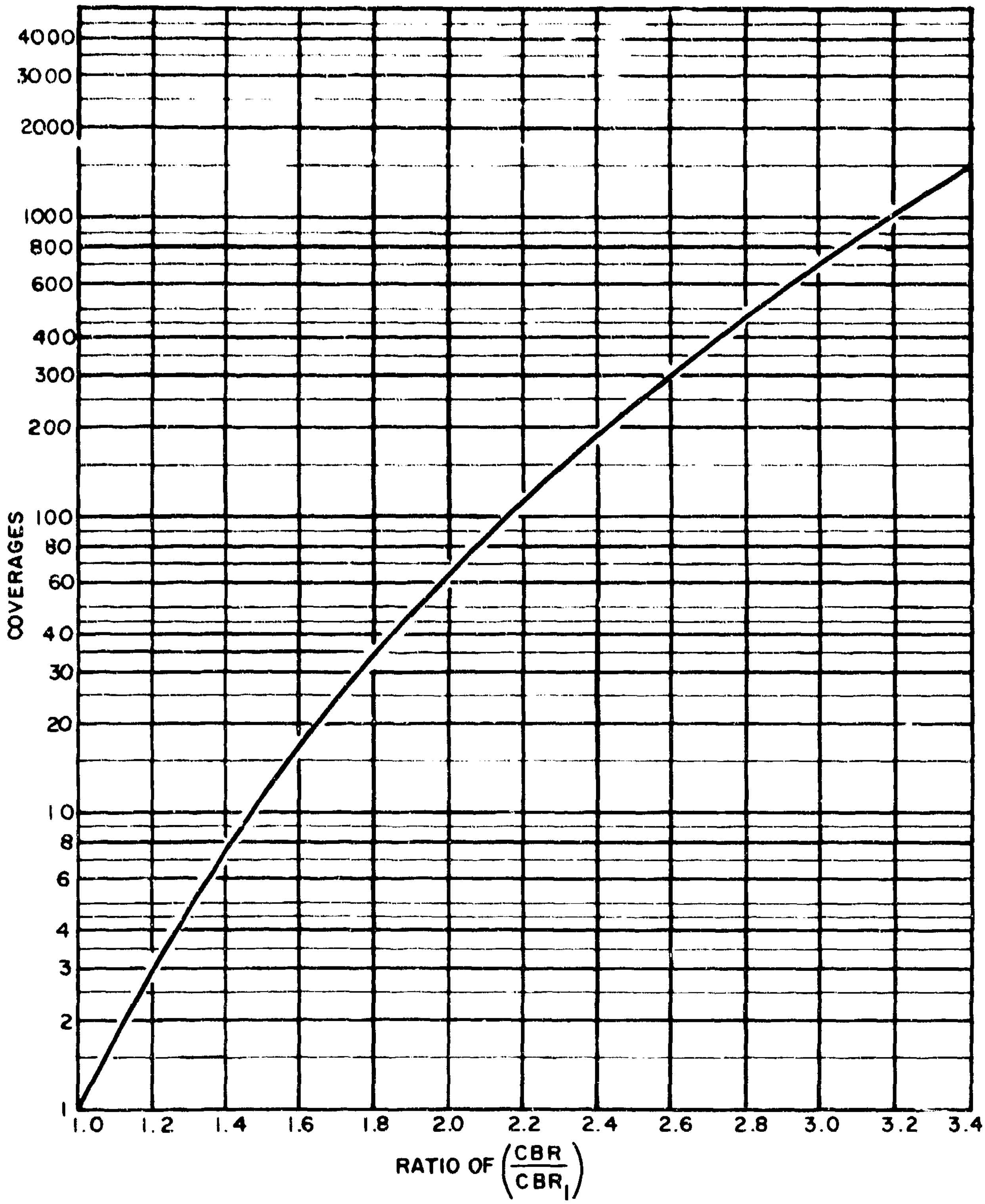
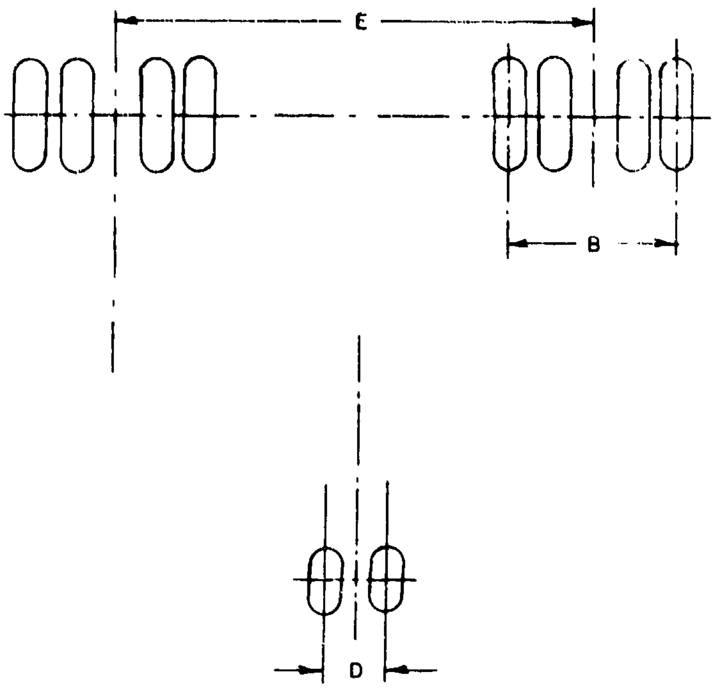


Figure 4. $\frac{CBR}{CBR_1}$ - Coverages



PROCEDURE

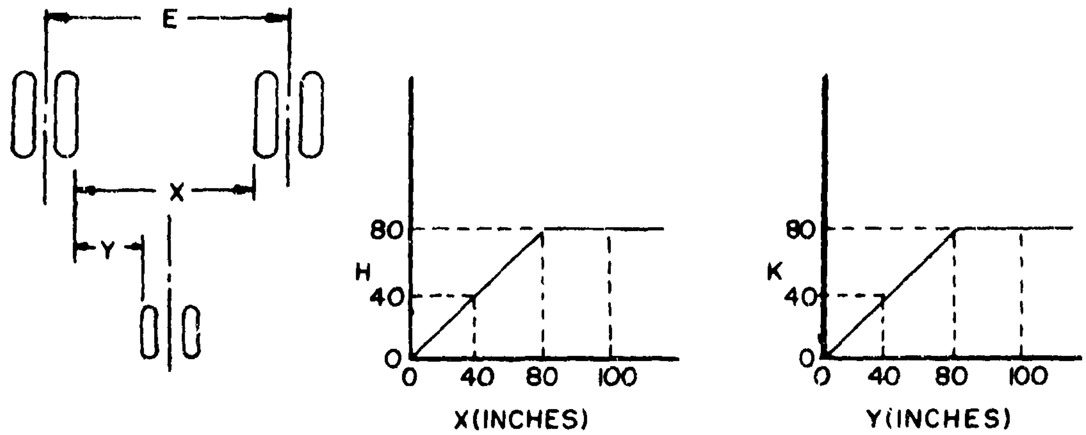
$$\text{Main Assembly: } P/C = \frac{B + 80 + W_M}{(0.75)\,(N_M)\,(W_M)}$$

$$\text{Nose Assembly: } P/C = \frac{D + 80 + W_N}{(0.75)\,(N_N)\,(W_N)}$$

SYMBOLS

P/C	Passes per coverage
N_M	Number of tires per main gear assy
N_N	Number of tires per nose gear assembly
W_M	Width of main single tire contact area $W_M = 0.874\sqrt{A_M}$
W_N	Width of nose single tire contact area $W_N = 0.874\sqrt{A_N}$
A_M	Single tire contact area of main tires
A_N	Single tire contact area of nose tires

Figure 5. Passes Per Coverage



(A) (B) (C)

PROCEDURE

1. Determine dimension

$$X = E - W_M - B$$

$$Y = \frac{E - W_M - W_N - B - D}{2}$$

2. Use figure (B) to determine "H" and figure (C) to determine "K"

3. Compute:

$$AP_M = \frac{80\ P_M\ P_N}{80\ P_N + (80 - H)\ P_N + (80 - K)\ P_M}$$

$$AP_N = \frac{80\ P_M\ P_N}{80\ P_M + (80 - H)\ P_N + (80 - K)\ P_N}$$

Where

P_M = allowable passes for the main gear

P_N = allowable passes for the nose gear

4. The allowable number of aircraft passes (AP) is then equal to the smaller value, AP_M or AP_N.

5. All dimensions are in inches.

Figure 6. Aircraft Passes

REFERENCES

1. D. Ladd and H. Ulery Jr., Aircraft Ground Flotation Investigation, Part I, AFFDL-TR-66-43, Part I, Wright-Patterson Air Force Base, Ohio Aug 1967.

2. Handbook of Instructions for Aircraft Design (HIAD), AFSCM 80-1.

3. "Subgrade, Subbase, and Test Method for Pavement Base-Course Materials," MIL-STD-621.

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